System F6

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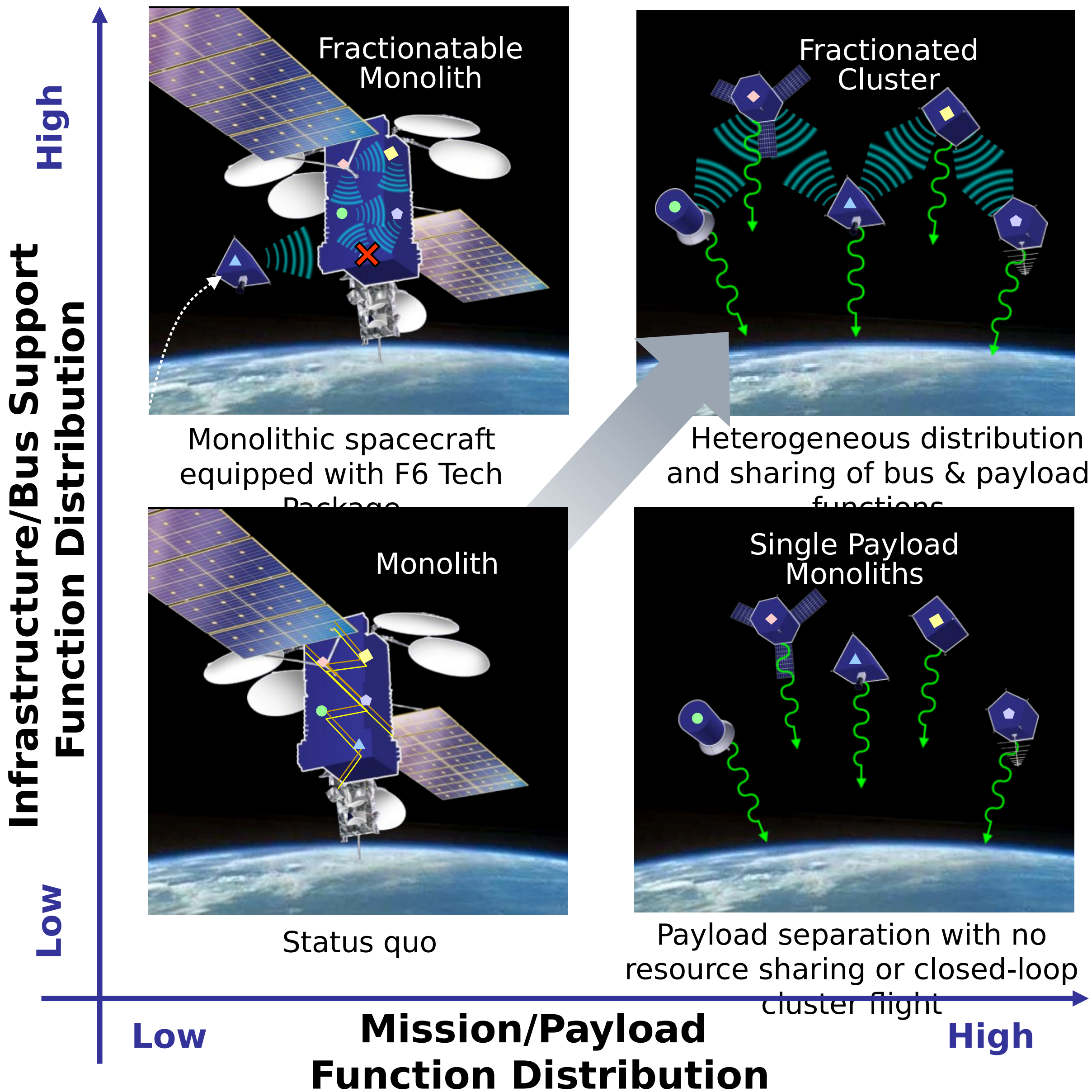
Program Overview Briefing

08 June 2011

Fractionated Space Architectures



Enablers of Fractionated Space Architectures

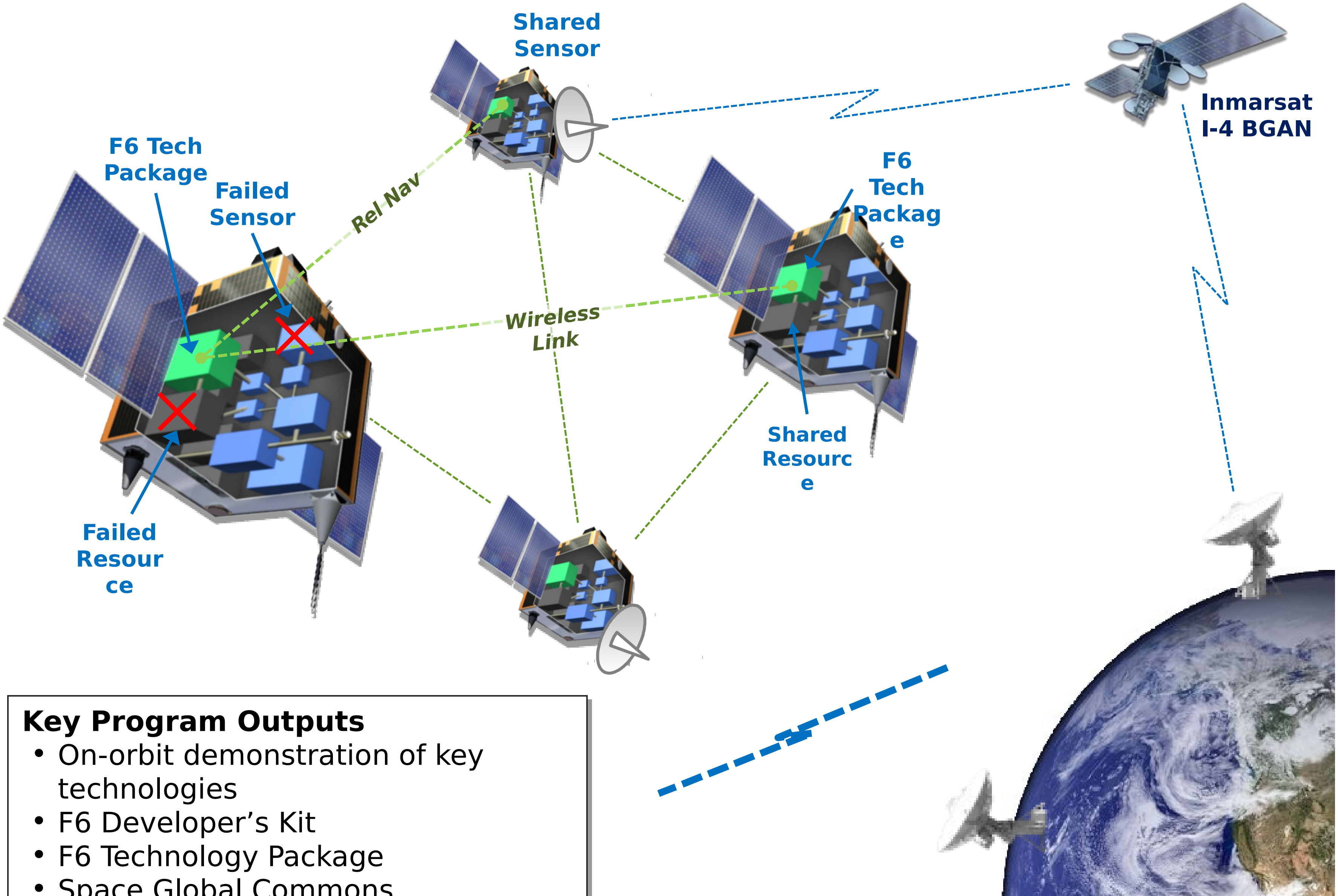
- Cluster maintenance
- Rapid cluster maneuvering
- Relative navigation
- Wireless networking
- Real-time resource sharing
- Multi-level security

- 24/7 LEO-ground connectivity

- Open F6 Developer's Kit
- Modular F6 Tech Package

- Adaptability Metrics

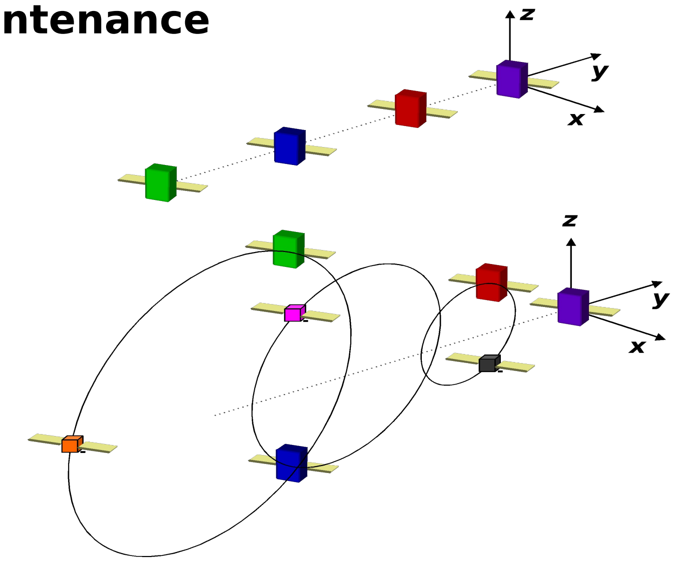
System F6 Demonstration Concept



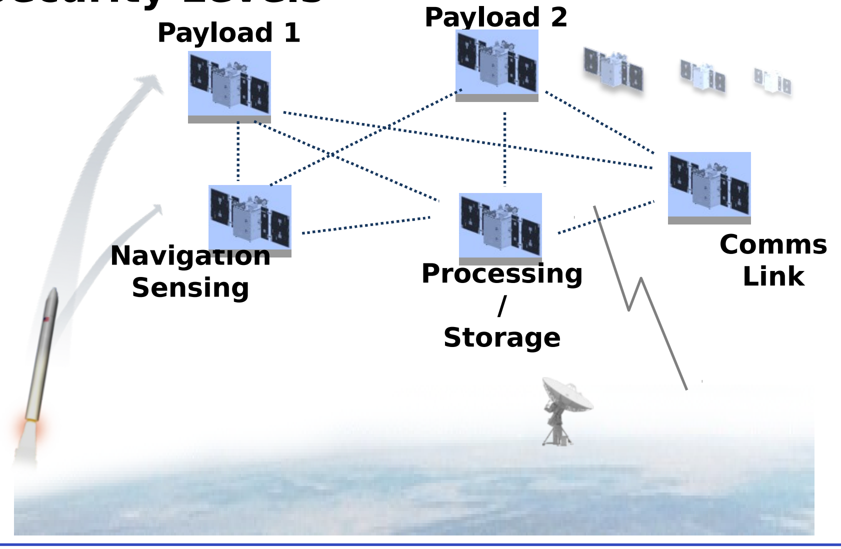
Key Program Outputs
- On-orbit demonstration of key technologies
- F6 Developer's Kit
- F6 Technology Package
- Space Global Commons

Key Capabilities for On-Orbit Demonstration

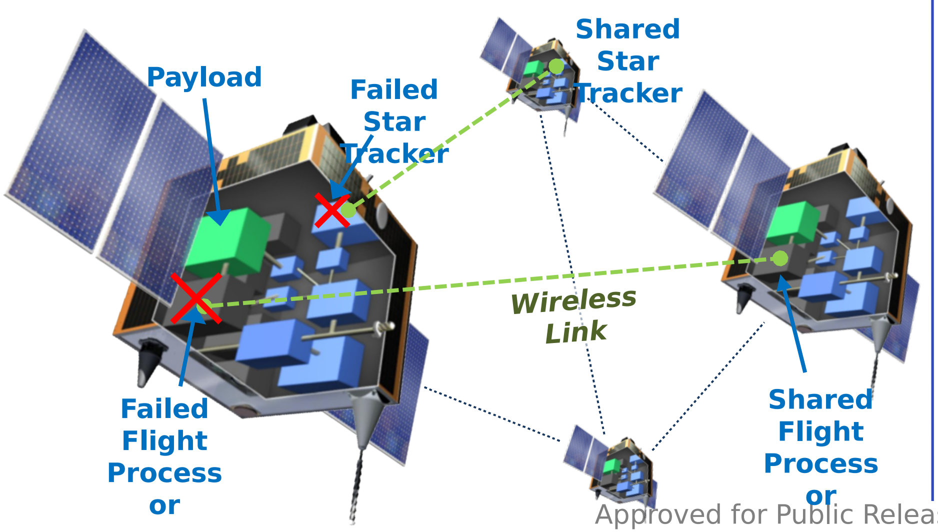
Demo 1: Long-Duration Cluster/Network Maintenance



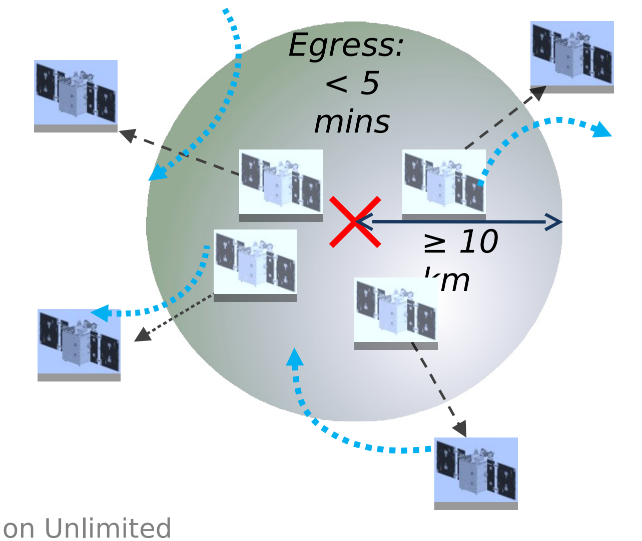
Demo 2: Resource Sharing at Multiple Security Levels



mo 3: Cluster-Level Fault Tolerance



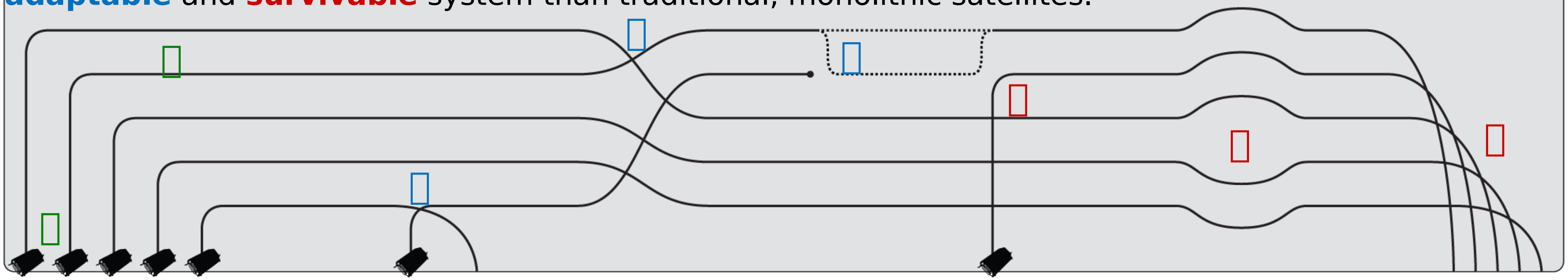
Demo 4: Defensive Scatter and Re-Gather



Military Utility of Fractionated Architectures

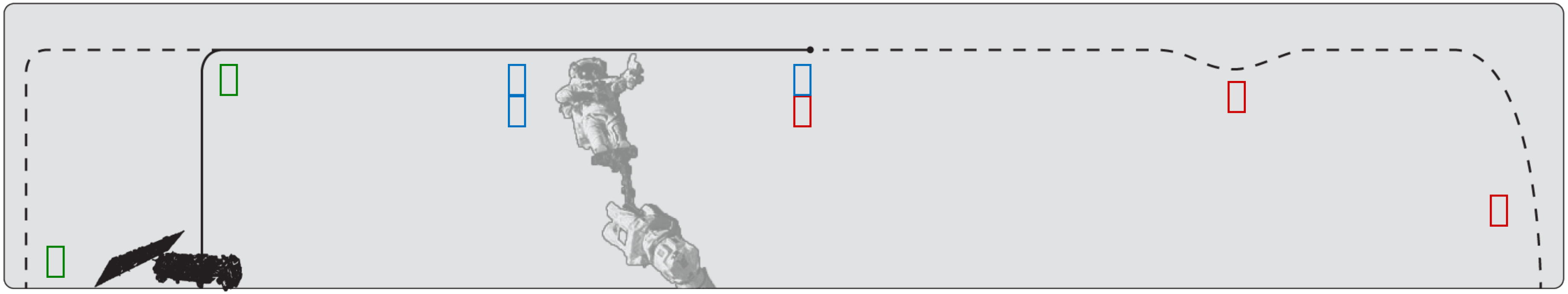
Fractionated System

F6 combines the strategies of distribution, modularization, and servicing into a single architecture, creating *virtual spacecraft* made up of free-flying, wirelessly networked elements. In addition to diversifying cost, schedule, and performance **risk**, this approach provides a more **responsive**, **adaptable** and **survivable** system than traditional, monolithic satellites.



- Incremental deployment
- Utility accrues before all pieces on orbit
- Component upgrade/replacement possible
- Reconfigure for different missions
- Cluster-level redundancy
- Replace failed components
- Scatter to avoid attack or debris
- Graceful degradation

Monolithic System



- Single component can delay launch
- No utility until entire system is launched
- Upgrades rarely feasible
- Capabilities strictly set
- No system-level redundancy
- Failure of any part may prove catastrophic
- Larger target is more vulnerable
- Capability ends abruptly

Program Philosophy

- Focus on architecture development, standards, and protocols
- Make information assurance a centerpiece of the architecture
- Write the software first, including new design tools, and plan for Verification & Validation
- Target best-of-class performers, including non-traditional and international
- Everything is open-source and maximally ITAR-free
- Build a community around the technology; use it to build the standard

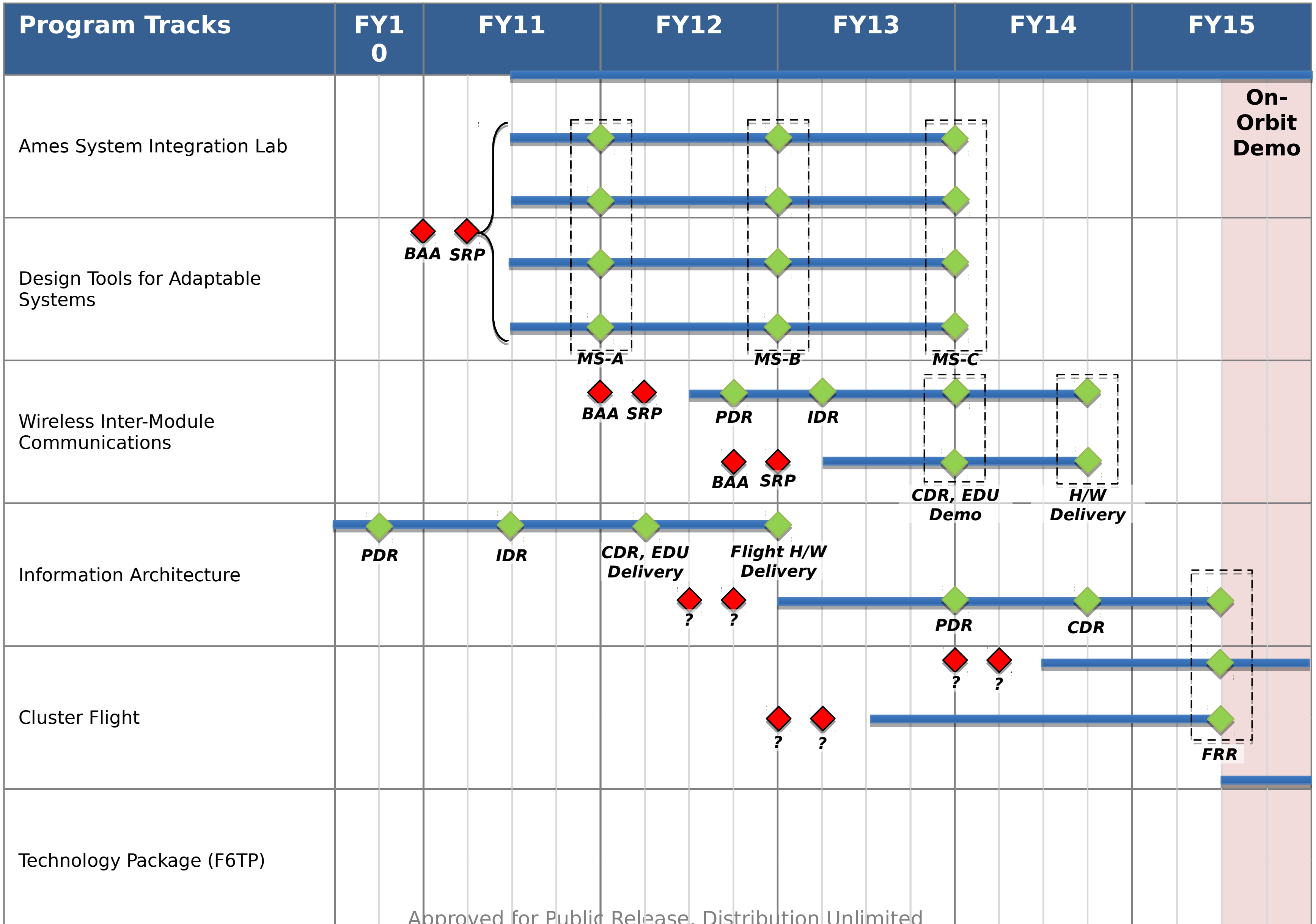
Program Structure – Top-level Goals

- Demonstrate the feasibility and benefits of replacing large monolithic spacecraft with a cluster of wirelessly-interconnected modules capable of sharing/utilizing resources.
- Develop open interface standards (FDK) that enable a space “global commons” for the sustainment and development of future fractionated systems
- Develop technology packages (F6TP) that can be installed on a wide range of spacecraft buses to enable them to fully participate in a fractionated cluster.
- Develop a space-based transceiver to utilize existing Broadband Global Area Network (BGAN) service of the Inmarsat network.
- Functional demos
  - Semi-autonomous long-duration maintenance of a cluster and network and ability to add or remove modules.
  - Securely share resources across the cluster network with real time guarantees across multiple security domains.
  - Autonomously reconfigure the cluster for safety and mission

Program Structure – Artifacts

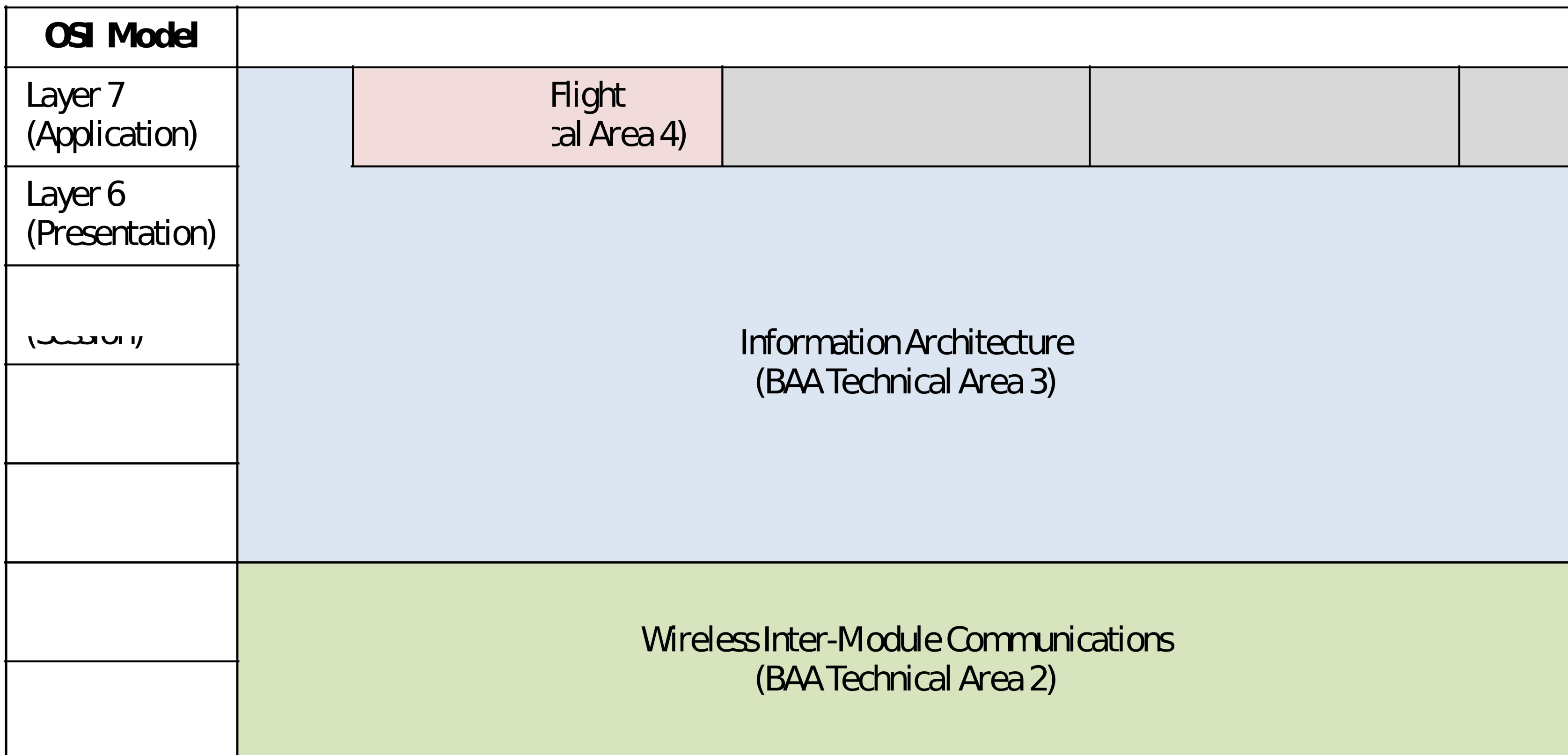
- F6 Developer’s Kit – everything needed for an independent third party to develop a module that can fully participate in a fractionated cluster
  - Interface standards, protocols, software, behaviors/rules
  - Reference implementation
  - Freely distributed under an open source license
- F6 Tech Package(s) – modular physical instantiation of the FDK that enables a spacecraft bus to become a fractionated cluster module
  - Cross-link, protocol stack, middleware, cluster flight software
  - Multiple sources, capable of supporting multiple bus types
  - Goal is for a fully productized commercial off-the-shelf item
- Shared Resource Payloads (e.g., Inmarsat SB-SAT)
- Spacecraft Buses
- Launch Vehicle(s)

Program Schedule



System F6 Technical Areas

- Four key enabling technologies:
  - Design Tools for Adaptable Systems
  - Wireless Inter-Module Communications
  - Information Architecture
  - Cluster Flight



Design Tools for Adaptable Systems

- Scope
  - When does the business case for fractionated architectures close?
  - When it does close, how should a system be optimally fractionated?
  - Quantitative measure of adaptability
  - Quantitative trade-offs between adaptability and traditional system attributes (size, weight, power, cost, performance, etc.)
- Deliverables
  - Milestone A: Algorithm development complete, prototype implementation
  - Milestone B: Fully-functional, polished, well-documented, user-friendly tool
  - Milestone C: Tool validated against real data sets

Wireless Inter-Module Communications

- Scope
  - Layers 1 and 2* inter-spacecraft wireless communications for up to 20 modules
  - Looking for interesting point solutions—no specific performance requirements
  - Ranges and data rates of interest: 100 m to 100 km, 100 kbps to 10 Gbps
  - Interested in throughput, availability, scalability, size, weight, power, pointing requirements, interference resistance, detection range
- Deliverables
  - Milestone A: Preliminary design, parametric model, draft FDK
  - Milestone B: Detailed design, full terrestrial prototype test, final FDK
  - Milestone C: Four complete flight-ready units

** Layer numbers refer to the OSI Reference Model*

Technical Area Three

Information Architecture

- Scope
  - Layers 3 through 7 information architecture for space and terrestrial network
  - Expose spacecraft and terrestrial devices as network-addressable nodes
  - Provide real-time distributed resource sharing across multiple security domains
  - Real-time fault tolerance, i.e., network and resource reconfiguration to maintain safety-critical functions and gracefully degrade mission capability
  - Additional considerations:
    - Throughput of available space-capable hardware
    - Principal security controls corresponding to DCID 6/3 PL5
    - Link encryption requirements—details TBD
    - V&V approach for distributed dynamic systems
- Deliverables
  - Milestone A: Preliminary design, draft FDK
  - Milestone B: Detailed design, complete implementation, final FDK

Cluster Flight

- Scope
  - Long-duration semi-autonomous cluster ops for up to 20 modules
  - Autonomous rapid maneuvering capability—defensive scatter (20 km, 5 mins)
  - Holistic approach to collision avoidance—safe to most probable failure modes
  - Looking for interesting point solutions—no specific performance requirements
  - Cluster size range of interest: 100 m to 100 km
- Deliverables
  - Milestone A: Preliminary design, parametric model, draft FDK
  - Milestone B: Detailed design, complete implementation, final FDK
  - Milestone C: V&V for flight

DARPA Team

- TA1: Design Tools for Adaptable Systems
  - Catholic University of America (CUA)
  - Palo Alto Research Center (PARC)
  - Caltech Jet Propulsion Laboratory (JPL)
  - Stevens Institute of Technology
  - Univ of So Cal Info Sciences Inst (USC/ISI)
- TA2: Wireless Inter-Module Communications
  - Aeronix
  - Argon ST
  - Southwest Research Institute (SwRI)
  - Space Micro
- TA3: Information Architecture
  - Carnegie Mellon University (CMU)
  - Vanderbilt University
  - QinetiQ North America
  - mZeal Communications
  - Raytheon BBN
  - Referentia Systems
  - University of Pittsburgh
  - Univ of So Cal Info Sciences Inst (USC/ISI)
- TA4: Cluster Flight
  - Microcosm
  - Aurora Flight Sciences
  - Northrop Grumman
  - Emergent Space
- Other Performers
  - Inmarsat Navigation Ventures Ltd (INVL)
  - Naval Postgraduate School (NPS)
  - Johns Hopkins Appl Physics Lab (JHU/APL)
- Government Team
  - NASA Ames Research Center
  - Naval Research Laboratory
  - Booz Allen Hamilton
  - Kinsey Technical Services (KTSi)
  - Oxford Systems Inc
  - RKF Engineering
  - Value-Driven Design Institute
  - National Security Agency (NSA)

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